ERDC/CRREL SR-14-3

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Engineering for Polar Operations, Logistics, and Research (EPOLAR)

Preliminary Guidelines and Standard Operating Procedure for Drainage and Erosion Control at McMurdo Station

Rosa Affleck and Meredith Carr

December 2014

Approved for public release; distribution is unlimited.

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Abstract

During the austral summer, the snowmelt runoff at McMurdo Station is quite unique and variable. As the temperature gradually warms up, McMurdo staff clears winter snow and ice accumulation in the drainage channels to accommodate the incoming snowmelt runoff. This ephemeral flow is observed as diurnal daily fluctuation throughout the austral season and varies depending on the air temperature and many other factors. In addition, the runoff mobilizes sediment that is washed into these channels and transports contaminants into to Winter Quarters Bay and McMurdo Sound. The overall goal of this document is to provide guidance for operation and maintenance of in-town roads and the drainage system. The processes and steps referred to in this document require further verification to incorporate lessons learned and to promote appropriate best practices.

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Preface

This study was conducted for the National Science Foundation (NSF), Division of Polar Programs (PLR), under Engineering for Polar Operations, Logistics, and Research (EPOLAR) EP-ANT-13-04, “McMurdo Drainage Design Solutions.” The technical monitor was George L. Blaisdell, Chief Program Manager, NSF-PLR, U.S. Antarctic Program.

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COL Jeffrey R. Eckstein was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Acronyms and Abbreviations

CRREL	Cold Regions Research and Engineering Laboratory
EPOLAR	Engineering for Polar Operations, Logistics and Research
ERDC	U.S. Army Engineer Research and Development Center
NSF	National Science Foundation
O&M	Operations and Maintenance
PAH	Polycyclic Aromatic Hydrocarbons
PLR	Division of Polar Programs
SOP	Standard Operating Procedure
SPAWAR	Space and Naval Warfare Systems Command
WQB	Winter Quarters Bay

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	0.0254	meters

1 Purpose and Applicability

Current practice by operations and maintenance (O&M) staff at McMurdo Station, Antarctica, to mitigate and minimize erosion is conducted without guidance nor a cohesive standard operating procedure (SOP). The current practice uses a reactive approach, using heavy equipment to widen ditches, to divert excess runoff to other areas, and to place temporary berms to contain the flow. This reactive approach may work temporarily and create fewer infrastructure disruptions; however, it is insufficient to prevent significant sediments (soil fines) and pollutants from running into Winter Quarters Bay (WQB) and McMurdo Sound.

The purpose of document is to establish steps and outline processes for an SOP necessary

- to reduce the erosion of material (soils or fines) by snowmelt runoff,
- to control flow velocity in channels during extreme runoff events, and
- to adopt applicable and effective engineering solutions and maintenance practices.

The processes and steps highlighted are intended for implementation by operational staff (part of the Antarctic Support Contract) and decision makers (the National Science Foundation) with the goal of incorporating various best management practices and using operational attention as proactive approaches to managing summertime runoff at McMurdo. Although staff members are experienced and knowledgeable regarding the timing for operation and maintenance of the drainage systems at the Station, this document emphasizes other factors that may help to predict significant discharge.

This SOP was developed based on our data measurements and analyses, documented by Affleck (2013) and Affleck et al. (2012a, 2012b, 2013, 2014a, 2014b, 2014c) at the Cold Regions Research and Engineering Laboratory (CRREL), U.S. Army Engineer Research and Development Center (ERDC), Hanover, NH.

This SOP document is organized as follows:

- The *Executive Summary*, Section 2, highlights the background, summary, and recommendations compiled from the studies and analyses of snowmelt runoff and its impacts on drainage at McMurdo Station (Affleck 2013; Affleck et al. 2012a, 2012b, 2013, 2014a, 2014b, 2014c).
- The *Practices and Procedures*, Section 3, addresses the procedural processes and steps for operation and maintenance of the drainage system.

The overall goal of this document is to provide guidance for operation and maintenance of in-town roads and the drainage system at McMurdo Station. The processes and steps referred to in this document (Section 3) will require validation to incorporate lessons learned and to promote the best practices.

2 Executive Summary

This section summarizes field measurements, data analyses, and modeling studies. More detailed information for this section can be found in Affleck (2013) and Affleck et al. (2012a, 2012b, 2013, 2014a, 2014b, 2014c).

2.1 Background

During austral summer, runoff at McMurdo Station is quite unique and variable. Melting of snow and glacier ice is the primary driver of this runoff (Affleck et al. 2012a). The major drainage paths at McMurdo Station are typically filled with snow and ice during the winter months. To accommodate the incoming snowmelt runoff as the temperature gradually rises, O&M staff manually clears winter snow and ice accumulation in the drainage channels by using manpower and heavy equipment. The drainage system at McMurdo Station was not holistically or appropriately designed, and it seemed to be an afterthought when the Station was developed. Snowmelt runoff passes through the Station via a system of drainage ditches, gullies, and culverts. The major flow paths are well-defined, earthen ditches that cross under the existing roads via culverts (Affleck et al. 2012b). Ice accumulates in culverts; and to accommodate major runoff, O&M removes ice from a couple of major culverts by using controlled blasting (using explosives) and flushing the ice with high water pressure. A few culverts have heat trace system installed to eliminate ice accumulation, but not all of them function properly. Some culverts are rusted while others are under-designed. Most of these drainage channels have steep sides or embankment slopes and steep in-channel gradients, causing an increased runoff velocity and channel embankment instability. Ultimately, the snowmelt runoff discharges directly into WQB and McMurdo Sound at several outlets.

The McMurdo Station watershed is one of the southernmost basins that annually experiences active water flow (Figure 1). The watershed is divided into six basins. Three major sub-basins (1, 2, and 3) are located north of the Station and are largely covered with a perennial snow and glacial cover. The other three sub-basins (5, 6, and 7) are relatively small. Sub-basin 1 drains the area from the west along Hut Point Ridge and Arrival Heights, then along the road, and down Hut Point Road. Sub-basin 2 has

the largest area and encompasses the majority of the snowfield and the depression above Gasoline Alley. Sub-basin 3 includes the area north of the Main Road, then adjacent to Crater Hill, loops around a portion of the snowfield, and continues on the east at the T-Site. Snowmelt runoff from sub-basins 2 and 3 merges downstream into WQB. Sub-basin 5 drains the area around the dorm, along the road towards the bay, and below the Water Treatment Plant. Sub-basin 6 is composed of the area south of the dorms and Main Road, along the road to the Chalet, and down to the road along the bay. Sub-basin 7 is the area south of the fuel tanks, around Observation Hill, and below the Helo Pad.

The soil at McMurdo is permeable and derived from weathered volcanic rocks that are primarily gravel with minimal fines (i.e., sand and silts). The soil has no organic content. Subsurface temperature measurements by Affleck et al. (2012a) found that a permeable active layer exists between 15.2 and 30.5 cm (6 and 12 in.), underlain with cemented-ice materials (i.e., permafrost). Affleck et al. (2012a) found that lateral flows from ice melting in the subsurface (i.e., active layer) occurred above and along the impermeable frozen soil layer.

Soil freeze–thaw action disrupts soil structures, displaces soils particles, and creates voids both in seasonally frozen and permafrost areas, especially when the soil strata do not have organic support or cohesion. The phenomenon weakens the soils structure and leads to erosion and instability, typically in banks and slopes (Gatto 1995; Rollings and Rollings 1996). Bank soils can be highly erodible and unstable during the melting season, owing to excessive pore water pressure and disrupted soil structures, creating mass failures. At McMurdo, a 2009–2010 study (Affleck et al. 2012a) observed soil water piping (i.e., water flows through the coarse-grained permeable soil strata, discharging along the bank face). This was caused by excess pore water pressure. Soil piping removes soil particles from their in-situ position, leaving voids in the subsurface and weakening it as a result.

Frozen soils cannot be compacted satisfactorily, especially those with high ice content (Andersland and Ladanyi 1994). Ice just below the surface and partly in the subsurface melts during warm months. Because of ground variations, this condition creates depressions or low spots that cause meltwater to pond. This situation is common in some areas at McMurdo

Station and can be found near or around buildings. In some cases, these areas are hard to get into with equipment because of utility pipes and other obstructions.

Figure 1. McMurdo Station watershed and sub-basin boundaries (after Affleck et al. 2012a).

Snowmelt runoff at McMurdo Station is caused by a truly dynamic processes in which the flow fluatuates diurnally in response to solar and tempetature input. The Affleck et al. (2014a) study developed a discharge curve rating for each channel by using the combined flow data measurements and establishing an estimate of the continuous flow along the major channels for the entire austral summer of 2010–2011. The Affleck et al.

(2014a) study quantified the frequency and probability distribution of the flow to determine the probability of occurrence of certain levels of discharge; the information provided the statistical distribution of flow to characterize the occurrence of certain levels of discharge. Lastly, Affleck et al. (2014a) related the timing of the runoff and peak flow to the maximum temperature and cloud cover. The cloud cover was used to calculate the percent clearness for infering the solar input. Based on a threshold clearness criterion and an observed correlation between the change in accumulated thawing degree days and peak temperatures, the lag time for when the peak discharge occurs can be estimated from observed climate data. Peak discharge appears to occur from 4 to 14 days after a peak temperature (Affleck et al. 2014a). These climate data predicting when peak discharges will occur are critical for operation, maintenance, and planning purposes.

The drainage channels intersect areas where vehicles are parked and also pass through a fuel pump location. When flow occurs, and especially during these high flow events, soil (particularly soil fines) and contaminants from day-to-day activities or from previous fuel spills move through these drainage paths and out to McMurdo Sound. The actual movement of pollutants through these drainage paths showed that the runoff contained significant concentration of contaminants (Affleck et al. 2014b). Pollutants analyzed included heavy metals, polycyclic aromatic hydrocarbons (PAHs), total hydrocarbons, and volatile organic compounds. Sources of these contaminants are likely from areas where significant operational or day-to-day activities are performed, including cargo storage, equipment and materials storage pads, roads, and parking spaces. Given that the snowmelt runoff contained significant concentration of heavy metals and certain PAHs, prevention and mitigation are crucial for reducing contamination at McMurdo Station.

The daily air-temperature fluctuations at McMurdo depict several warming events occurring during the summer months (Figure 2). The warming and cooling trends observed in the 2009–2010 and 2010–2011 austral summers reflected these historical trends in temperature variations (Figure 3 shows maximum daily temperature). Warming events can occur as early as the first week of November (see summer 2010–2011) but are most common and have the most significant impact on flow in December and January.

Figure 2. Average maximum and minimum daily temperatures, 1973–2008 (after Affleck et al. 2012a).

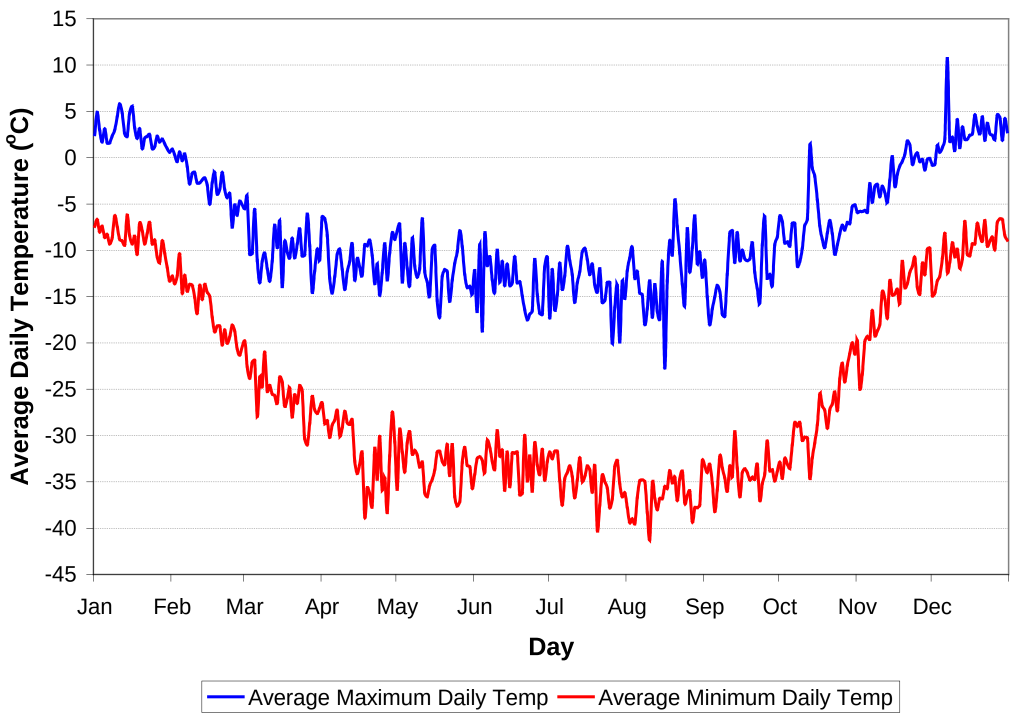


Figure 3. Maximum summer temperatures at McMurdo, several years of record (after Affleck et al. 2014a). The black line at 0°C is the melting point.

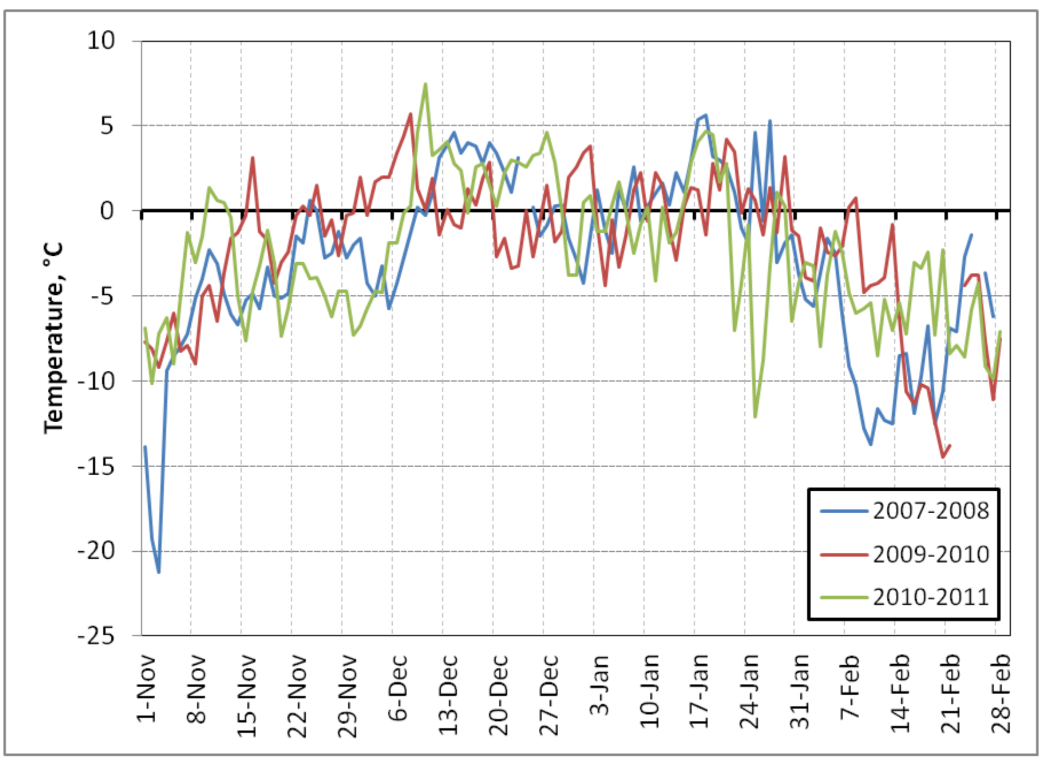
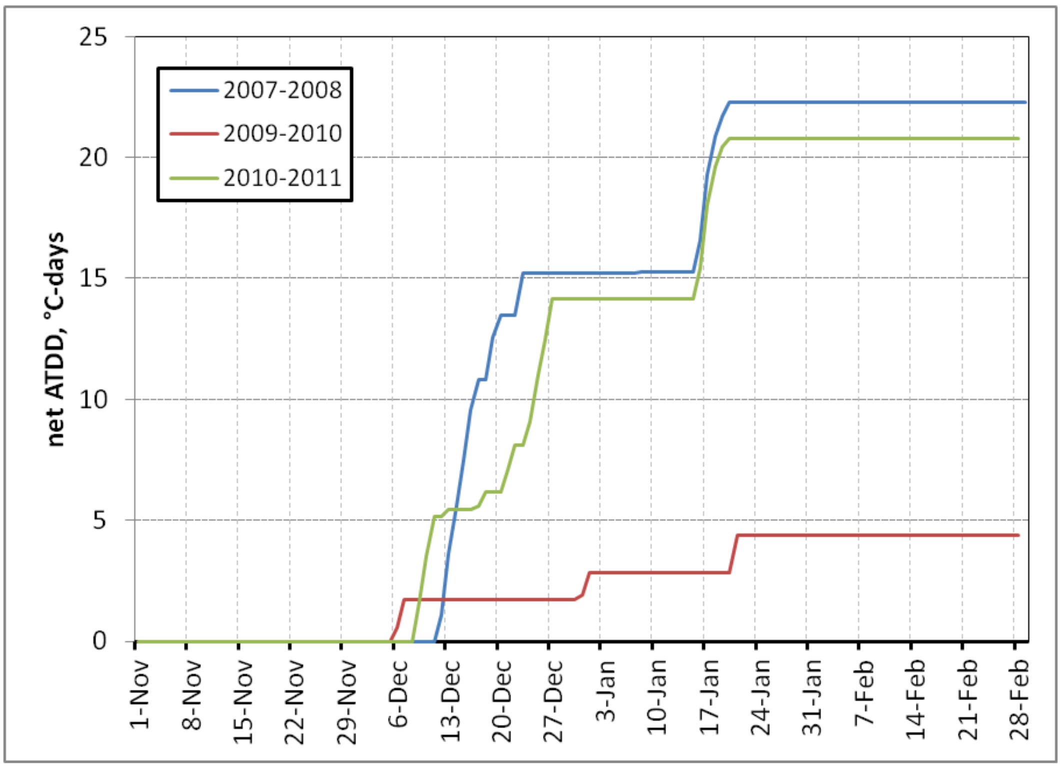


Figure 4 shows the net accumulated thawing degree-days ($ATDD_{net}$), or the cumulative number of degree-days when the average daily air temperatures are above 0°C. Each time the $ATDD_{net}$ rises, it indicates a warm spell; and the magnitude of the warm spell is indicated by the amplitude of the rise. The data show that 2009–2010 was a much cooler summer but that 2007–2008 and 2010–2011 were very similar to 2009–2010 with a strong warm spell in mid-December (about 15°C-days and 1.5 weeks long) and a shorter, smaller warm spell in mid-January (about 7°C-days and 3–4 days long) (Figure 4).

Figure 4. Net accumulated thawing degree days when average daily air temperatures are above 0 °C, for three summers at McMurdo (after Affleck et al. 2014a).



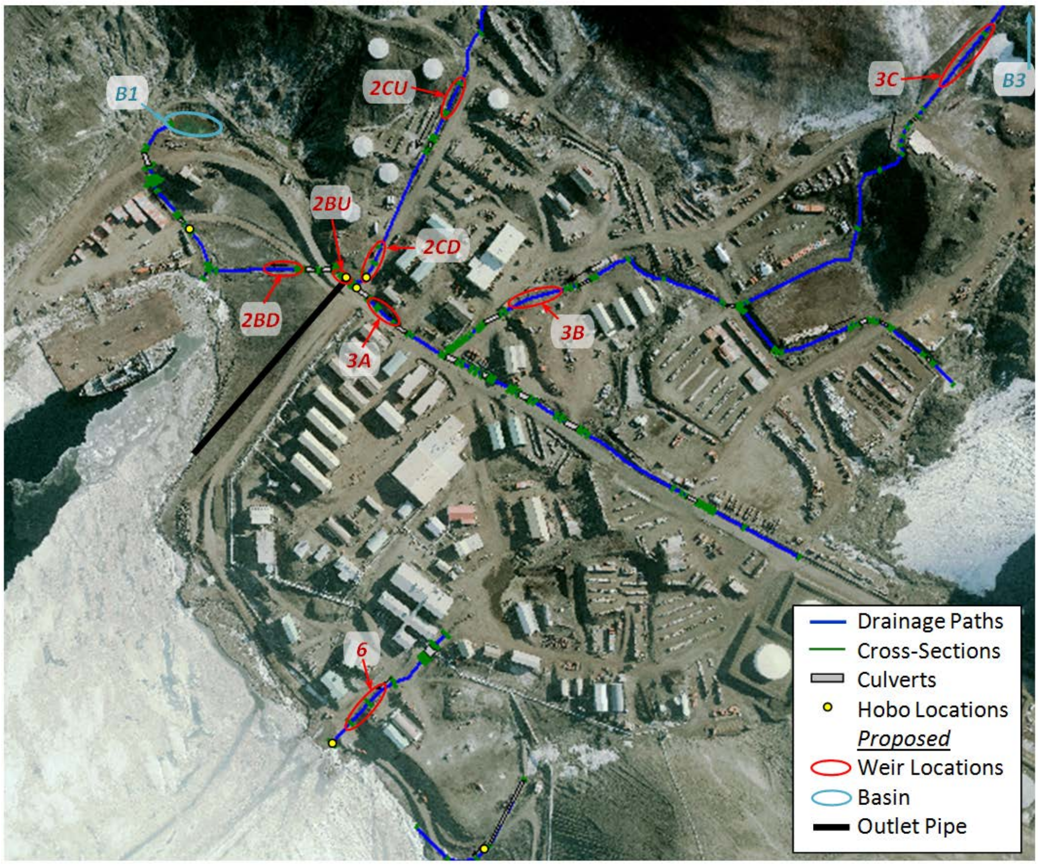
2.2 Results summary for the Affleck et al. studies

2.2.1 Snowmelt runoff distribution

The snowmelt runoff from sub-basin 2 discharges to the channel on Gasoline Alley while the snowmelt runoff from sub-basin 3 drains into roadside ditches with flow that is routed down along the Main Road (Figure 5). The runoff from sub-basins 2 and 3 merges into the channel labeled 2BU and continues along 2BD in Figure 5. The critical channels at McMurdo Sta-

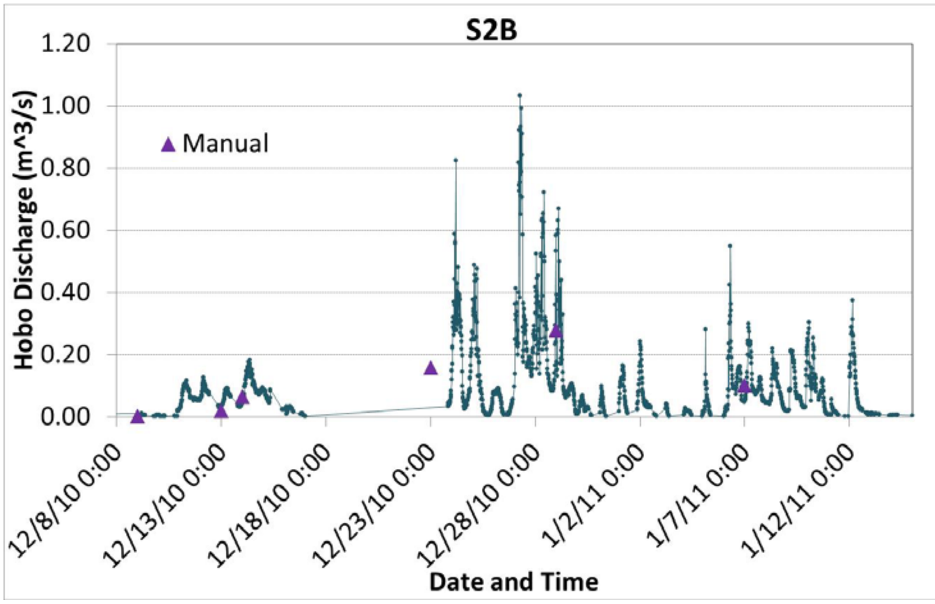
tion with significant runoff include S2C (along the Gasoline Alley, labeled as 2CD and 2CU in Figure 5, runoff from sub-basin 2) and S3A (the channel along the Main Road), which merge into S2B (channel labeled 2BU, runoff from sub-basin 3).

Figure 5. McMurdo Station drainage system.



Snowmelt runoff has been observed as it starts to seep out of the surface and appear in the lower channels as early as the third week of November. Flow measurements were conducted during two austral summers: 2009-2010 (Affleck et al. 2012a) and 2010–2011 (Affleck et al. 2014). In general, the continuous flow rate in these critical channels depicted large diurnal variations. Based on the continuous runoff data during the summer of 2010–2011, the measurable runoff data started on 11 December; and then it fluctuated and subsided for days (Figure 6). These patterns continued with varying flow peaks throughout the season. The maximum flow rate at S2C (along Gasoline Alley, channel 2CD in Figure 5) of 0.44 m^3/s occurred on 22 December 2010. The estimated maximum flow at S2B (in channel 2BU in Figure 5) of 1.03 m^3/s occurred on 27 December 2010 (Figure 6).

Figure 6. Flow recorded during the 2010–2011 season at location S2B in channel 2BU from Fig. 5 (after Affleck et al. 2014a).



2.2.2 Flow variations and timing

An extreme runoff event occurred at McMurdo Station in mid-December 2007 with very limited warning or time to respond and resulted in significant erosion (Affleck et al. 2014a). When this incident occurred, operations and maintenance staff took a reactive approach to mitigate and minimize erosion by using heavy equipment to open and widen ditches, to reroute or divert excess runoff to other areas, and to place temporary berms to contain the flow. This reactive approach has been the main O&M procedure for responding to extreme events. Although runoff events as extreme as December 2007 do not occur often and have not been quantitatively recorded and probability analysis conducted from flow measurements during the austral summer of 2010–2011 indicated that flows greater than 0.33 m^3/s occur less than 5% of the time (Affleck et al. 2014a), events of this magnitude even only 5% of the time can cause significant damage that is easier prevented than repaired.

Knowing when runoff events occur in the summer is critical for proactive operation and maintenance of the drainage system. Affleck et al. (2014a) used air temperature and cloud cover as indicators to quantify the lag time and to identify when significant flow occurred. Indicators for air temperature were used based on the date when peak maximum temperature occurred, the start date when the temperature was above freezing for greater

than 3 consecutive days, and the corresponding maximum change (Δ_{max}) in $ATDD_{net}$ (in °C-days). The indicator for daily cloud cover is expressed in terms of clearness to represent the solar input. Clearness was evaluated as 100% minus the reported cloudiness (%) and used the maximum clearness over the first three days above freezing. Lag time is the indicator used to represent the time period between peak temperature and peak flow (in days).

Using the indicators approach, Affleck et al. (2014a) investigated data from two Austral summers: 2009–2010 and 2010–2011 (Table 1). A plot of lag time versus change in $ATDD_{net}$ suggests an exponential trend between the severity of the warm up (Figure 7) expressed as Δ_{max} $ATDD_{net}$ (°C-days) over three days around the peak temperatures and the lag time until peak flow occurs. The results provide a set of conditions such that peak flow can be expected about 10 days after a peak temperature and clearness exceeding 25%. For estimating the number of days until peak flow, the Δ_{max} $ATDD_{net}$ can be input into Figure 7 to establish an approximation for the lag time.

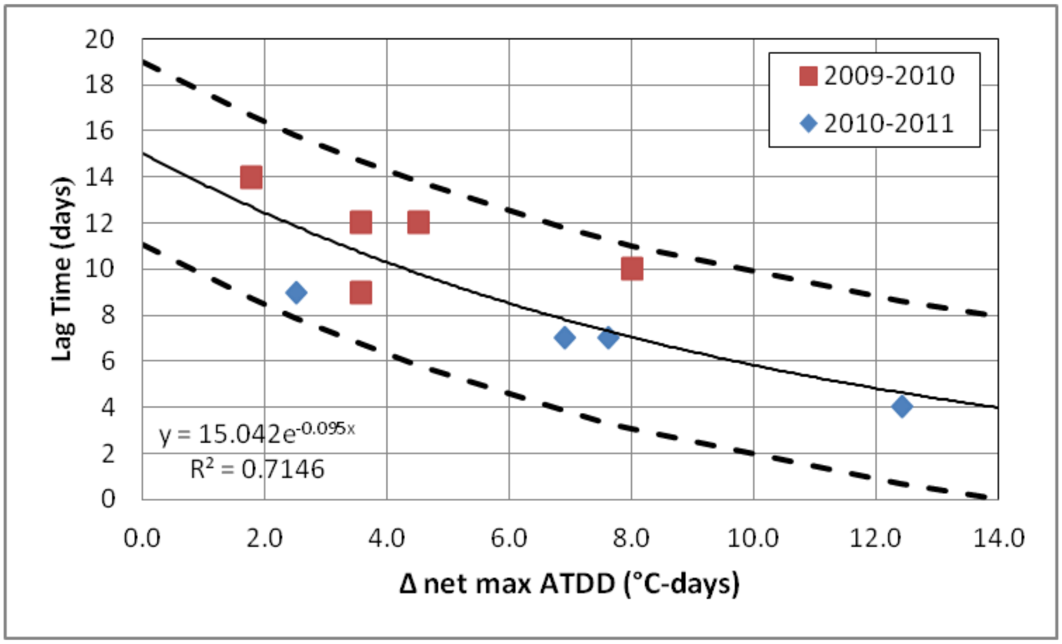
Table 1. Summary of warming events and their characteristics, 2009–2011.

Austral Summer	Date of Peak Temp	Max Temperature (°C)	Max Clearness over 3 Days	Δ_{max} $ATDD_{net}$ (°C-days)	Date of Peak Discharge Q	Magnitude of Peak Q (m³/s)	Δ Peak Temp to Peak Q (Days)
2009–2010	11/25	1.50	59%	1.5	12/9	4.89	14
	12/8	5.72	45%	7.0	12/17	3.41	9
	12/19	2.89	28%	2.9	1/2	1.87	14
	1/2	3.78	30%	3.8	1/11	1.29	9
	1/11	2.28	67%	3.8	1/23	2.87	12
2010–2011	11/10	1.39	64%	2.0	11/21	0.27	11
.	12/10	7.50	72%	10.8	12/14	0.18	4
	12/13	4.11	56%	6.9	12/24	0.82	11
	12/18	2.78	45%	4.3	12/27	1.03	9
	12/22	3.00	33%	5.9	1/2	0.24	11
	12/27	4.61	56%	7.5	1/6	0.55	10
	1/18	4.72	45%	9.2	1/24	0.54	6
		min	28%	1.5			4
		max	72%	10.8			14
		mean	51%	5.5			10

Q = Discharge

We have developed a spreadsheet to estimate when the peak discharge could occur by using the climate data available at McMurdo Station from SPAWAR (Space and Naval Warfare Systems Command, www.spawar.navy.mil) or through Antarctic Meteorological Research Center (http://amrc.ssec.wisc.edu). Populating the spreadsheet is discussed in Section 3.3.

Figure 7. Lag time between peak temperature and flow related to $\Delta_{max}\ ATDD_{net}$ with the 95% confident limits based on 1.96 times the standard error of the regression (black solid line).

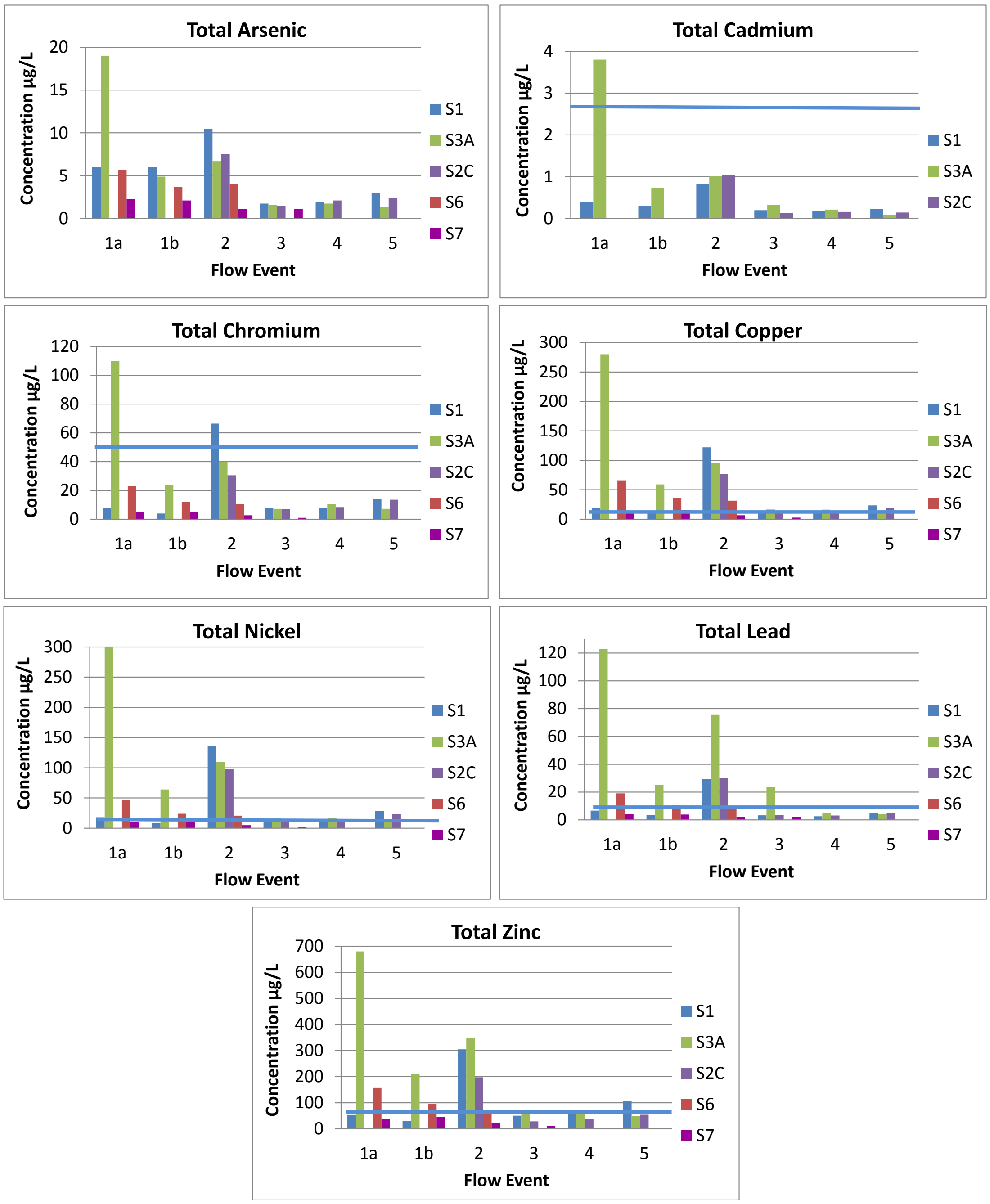


2.2.3 Pollutant concentration in runoff

To understand what types of analytes were present in the runoff and diverted into WQB, we used the limits for water quality to quantify pollutant concentrations. Five times during the 2010–2011 austral summer, water samples from the runoff were collected in locations S1, S2C S3A, S6, and S7 (Figure 1). These water samples were sent to a laboratory in New Zealand that analyzed them for pollutants, including heavy metals, PAHs, total hydrocarbons, and volatile organic compounds (Affleck et al. 2014b). The results characterized the concentration levels in the runoff at various locations during the first flush, peak flow of the first flush, and sequential major peak flow events of the season. Heavy metals were present in the water in all of the channels throughout the sampling events, and the concentrations for heavy metals were elevated during the first flush when flow began and during the first significant flow. The analytes of most concern at McMurdo Station included cadmium, chromium, copper, lead, nickel,

and zinc. Also, the concentrations for selected PAHs, such as acenaphthene, fluoranthene, fluorine, phenanthrene, and pyrene, were elevated during the first peak flow but diminished in the subsequent peak flows later in the season.

Figure 8. Concentration of heavy metals during flow events at channel locations S1, S2C S3A, S6, and S7 (after Affleck et al. 2014b). The blue line across the y-axis indicates the chronic limits for saltwater.



Using the limits from USEPA (2013) and Nagpal (1995) for acute and chronic exposure for aquatic life, Affleck et al. (2014b) found that cadmium, chromium, copper, lead, nickel, and zinc exceeded the chronic limit for aquatic water quality (saltwater) in several of the sampling locations (Figure 8). When these analytes are compared to their respective chronic limits for aquatic water quality, copper and nickel were 90 and 36 times their chronic limits during the first flush; Pb was measured at 15 and 10 times its chronic limit during the first flow and the first peak flow, respectively.

2.3 Mitigation recommendations

Given the variability of the snowmelt runoff with extreme flow rates and the significant concentration of pollutants in the runoff, one way to mitigate erosion is by implementing preventive approaches, such as best management practices or erosion control systems. These systems are often built to trap sediment and to control or attenuate flow in the receiving channels before the runoff exits into WQB at McMurdo Sound.

2.3.1 Flow control weirs

Affleck et al. (2014b) recommended porous weirs at all the locations indicated in Figure 5 (except 2BD). The porous weirs being proposed are rock check dams and wooden dams detailed below in the *Practices and Procedures* section. These weirs were designed for a given depth such that corresponding stresses met the allowable velocity and stable slope criteria. Affleck et al. (2014b) also examined the trapping efficiency as a function of porosity. Table 2 shows the recommended types of weirs at each drainage path based on site conditions and erosion criteria. Each of these flow control weir types has advantages and disadvantages and will be adapted for the unique conditions from freeze–thaw cycles experienced at McMurdo. These flow control weirs are designed so that they will be installed in the beginning of the runoff season and removed at the end of each season to allow for other O&M activities during the remainder of the year.

Table 2. Recommended weirs on selected reaches

Weir Location	Reach (m)	Length (m)	Typical Cross Section (m)	Number of Rock Weirs	Number of Wooden Weirs	Number of GeoRidges
W2BU	158–170	12	159.08	-	1	-
W2BD	44–100	66	78.799	-	-	-
W2CU	365–435	70	390.52	2	2	
W2CD	220–180	40	195.218	2	-	-
W3A	200–235	35	208.94	-	-	1
W3B	465–400	65	420.478	-	1	-
W3C	1070–965	105	992.807	1	1	-
W6	70–35	35	40.984	-	-	2–3

2.3.2 Culvert remediation

Table 3 details the Affleck et al. (2014b) study on culvert recommendations specific for particular locations (Figure 9), indicating the size, and information on its conditional capacity as of 2010–2011 information. Further work needs to determine the appropriate culvert replacement type (e.g., metal or plastic or concrete, etc.) and to try to standardize culverts around the Station.

Table 3. Existing qualitative culvert characteristics, conditions, and recommendations for mitigation. Colors are preliminary conditional coding: orange indicates that the culvert requires immediate attention; yellow indicates that the culver should be under consideration for attention. HW/D = headwater/diameter (or headwater to culvert diameter ratio); V = velocity.

Culvert	Location/Crossing Description	Sub-Basins Conveyed	Runoff Conveyed	Dimensions: Diameter Length Type	Physical Condition	Ice Conditions and Signs of Physical Decay	Quantitative Criteria							Possible Solutions
							Below Capacity, HW/D > 1	Under-designed Cover < 0.45	Scour Likely Upstream, V > 1.6	Scour Likely Downstream, V > 1.6	Likely Clogging, V < 1	Moderate Abrasion V > 3	> 25% increase in Downstream Velocity	
1	Pier Rd	2 and 3	70%	1 m (36 in.) 11.4 m corrugated metal	questionable	ice buildup is common; rust on the bottom	√	√	√	√		√		replace or repair, lower inlet, dig in inlet, and place rocks to stabilize and lower slope
2	Hut Point Road	2 and 3	66%	1.2 m (48 in.) 12.6 m steel box with wooden frame top	reasonable	ice buildup is common; blasted during 2009–2010 season due to ice blockage; blasting requires road closure and blast protection mat; rust on the metal	√		√	√				consider replacement with circular pipe, dig in or lower inlet to slow velocities and reduce energy, stabilize inlet and outlet with rock
3	Gasoline Alley	3	29%	0.9 m (35 in.) 15.8 m box	poor	prone to ice build-up; ice blocked flow in 2009–2010; utility pipes in the inlet required manual ice and snow clearing; outlet can be cleared by backhoe; sides are caving, bottom is covered with ice and soil, and top is stable	√		√	√				consider replacement with circular pipe, dig in or lower inlet to slow velocities and reduce energy, stabilize inlet and outlet with rock

Culvert	Location/Crossing Description	Sub-Basins Conveyed	Runoff Conveyed	Dimensions: Diameter Length Type	Physical Condition	Ice Conditions and Signs of Physical Decay	Quantitative Criteria							Possible Solutions
							Below Capacity, HW/D > 1	Under-designed Cover < 0.45	Scour Likely Upstream, V > 1.6	Scour Likely Downstream, V > 1.6	Likely Clogging, V < 1	Moderate Abrasion V > 3	> 25% increase in Downstream Velocity	
4		3	26%	0.61 m (24 in.) 11.5 m corrugated metal	moderate	heat trace emplaced; ice on bottom of culvert; bottom covered with ice and soil	√	√	√	√				increase diameter to increase capacity and to lower velocities; increase cover by placing the culvert lower or raising roadway
5		3	2.2%	1 m (36 in.) 16.5 m corrugated metal	working	heat trace emplaced; utility pipes across outlet required manual ice and snow clearing; bottom covered with ice and soil		√	√	√			√	increase roadway height to provide more cover; riprap protection at inlet and outlet; increase roughness to reduce downstream velocity
6	short cut to Bldg 140	3	2%	0.61 m (24 in.) 4.4 m corrugated metal	moderate	inlet and outlet clearing of the snow and ice build-up can be conducted using heavy equipment; outlet is pinched			√	√			√	add riprap protection at inlet and outlet; increase roughness to reduce downstream velocity
7	road to Bldg 140	3	1.7%	0.61 m (24 in.) 17.7 m corrugated metal	good	heat trace through the bottom of the culvert			√					add riprap protection upstream, or dig out some to slow inlet velocity
8		3	1%	1 m (36 in.) 18 m corrugated metal	poor	ice and snow build-up occurs in the culvert; heat trace runs the length of culvert; bottom weir aged, likely from heavy equipment; inlet wooden barriers require repair			√				√	add riprap protection upstream, or dig out some to slow inlet velocity; dig out downstream to provide smoother transition and let increase in downstream velocity

Culvert	Location/Crossing Description	Sub-Basins Conveyed	Runoff Conveyed	Dimensions: Diameter Length Type	Physical Condition	Ice Conditions and Signs of Physical Decay	Quantitative Criteria							Possible Solutions
							Below Capacity, HW/D > 1	Under-designed Cover < 0.45	Scour Likely Upstream, V > 1.6	Scour Likely Downstream, V > 1.6	Likely Clogging, V < 1	Moderate Abrasion V > 3	> 25% increase in Downstream Velocity	
9		3	0.8%	0.61 m (24 in.) 12.1 m corrugated metal	moderate	prone to snow and ice build-up; clearing can be conducted with heavy equipment								
10	across Heavy Shop parking lot to the ditch along Bldg 175	3B	15%	1 m (36 in.) 34.2 m corrugated metal	moderate	snow clearing for the inlet and outlet can be conducted with heavy equipment			√	√		√		reduce slope of culvert to reduce velocities and prevent scour and abrasion; provide inlet and outlet scour protection
11		3B	15%	0.61 m (24 in.) 12.3 m steel box	poor	snow and ice clearing is required at both inlet and outlet to permit flow; bottom has eroded and soil bottom is eroded, water flows underneath	√		√	√				replace or repair with larger culvert (currently undersized); smooth inlet and outlet conditions to a gentler slope and protect with rock or riprap.

Culvert	Location/Crossing Description	Sub-Basins Conveyed	Runoff Conveyed	Dimensions: Diameter Length Type	Physical Condition	Ice Conditions and Signs of Physical Decay	Quantitative Criteria							Possible Solutions
							Below Capacity, HW/D > 1	Under-designed Cover < 0.45	Scour Likely Upstream, V > 1.6	Scour Likely Downstream, V > 1.6	Likely Clogging, V < 1	Moderate Abrasion V > 3	> 25% increase in Downstream Velocity	
12		3B	1%	0.61 m (24 in.) 10.3 m steel box;	poor	ice accumulation occurs due to runoff being trapped; banks of the inlet and outlet of the culvert have eroded and failed; soil and ice are blocking the drainage path		√	√	√				repair or replace, repair banks and provide wooden or riprap protection; modify slopes to match or more smoothly transition to bed slope; increase roadway elevation or emplace replacement culvert deeper to ensure minimum cover
13	recessed behind the bollards	3D	21%	0.61 m (24 in.) 9.4 m corrugated metal	moderate	prone to snow and ice build-up; snow clearing for the inlet and outlet can be conducted with heavy equipment			√	√				provide scour protection at inlet and outlet
14	recessed behind the bollards	3D	7.2%	1 m (36 in.) 9.2 m corrugated metal	moderate	snow and ice buildup occurs and can be cleared with heavy equipment; debris from wood chips trapped in culvert			√	√				provide scour protection at inlet and outlet
15	flush with the bollards	3D	89%	1 m (36 in.) 5.5 m corrugated metal	moderate	snow and ice buildup occurs and can be cleared with heavy equipment		√						increase roadway height to provide the minimum cover and to protect structural stability

Culvert	Location/Crossing Description	Sub-Basins Conveyed	Runoff Conveyed	Dimensions: Diameter Length Type	Physical Condition	Ice Conditions and Signs of Physical Decay	Quantitative Criteria							Possible Solutions
							Below Capacity, HW/D > 1	Under-designed Cover < 0.45	Scour Likely Upstream, V > 1.6	Scour Likely Downstream, V > 1.6	Likely Clogging, V < 1	Moderate Abrasion V > 3	> 25% increase in Downstream Velocity	
16	buried beneath the catwalk between the Chalet and Crary Lab	6	0%	0.61 m (24 in.) 9.2 m corrugated metal	poor	drainage problems with severe ice accumulation; utility pipes crossing below the culvert outlet required manual clearing; inlet and outlet usually obstructed and buried by eroded soil; snow and ice buildup; at a tight location, inlet and outlet unmarked		√						appears that structural stability is compromised; recommend replacing or reshaping; consider heat trace; provide channel scour protection in channel upstream; increase cover in thin areas; reduce rock cover in areas that may be endangering structural stability due to weight
17	loading dock of Science Support Center (Bldg 4)			~0.3 m (12 in.) unknown insulated pipe	unknown	snow and ice build-up can be severe in this location due to snow drifting; snowmelt tends to accumulate upstream of the culvert inlet and creates ponding in the area								smooth elevation in ponding area; consider berm to reduce drifting; modify snow dump locations
18	from NW corner of the Power Plan to off the hill			0.61 m (24 in.) unknown corrugated metal	unknown	clearing the inlet and outlet of the culvert is difficult because they are located in a tight location								modify snow dump locations

Culvert	Location/Crossing Description	Sub-Basins Conveyed	Runoff Conveyed	Dimensions: Diameter Length Type	Physical Condition	Ice Conditions and Signs of Physical Decay	Quantitative Criteria							Possible Solutions
							Below Capacity, HW/D > 1	Under-designed Cover < 0.45	Scour Likely Upstream, V > 1.6	Scour Likely Downstream, V > 1.6	Likely Clogging, V < 1	Moderate Abrasion V > 3	> 25% increase in Downstream Velocity	
19	metal catwalk towards the Waste Water Treatment Plant			0.61 m (24 in.) unknown corrugated metal	unknown	clearing the inlet and outlet is difficult because they are located in a tight spot; tight location								modify snow dump locations
20	between the generator and off the hill on S of Waste Water Treatment Plant			0.61 m (24 in.) unknown corrugated metal	unknown	clearing the inlet and outlet is difficult because they are located in a tight spot; tight location								modify snow dump locations
21	the road by the VXE6 sea ice transition and below the Helo Pad			0.3 m (12 in.) unknown metal	poor	historically clogged; snowmelt ponds in the inlet causing water to overflow across the road								replace with a larger culvert to increase capacity or increase slope of culvert to move water more quickly through system and abrade accumulated sediments and ice preventing inlet ponding; consider placement of heat trace

Culvert	Location/Crossing Description	Sub-Basins Conveyed	Runoff Conveyed	Dimensions: Diameter Length Type	Physical Condition	Ice Conditions and Signs of Physical Decay	Quantitative Criteria							Possible Solutions
							Below Capacity, HW/D > 1	Under-designed Cover < 0.45	Scour Likely Upstream, V > 1.6	Scour Likely Downstream, V > 1.6	Likely Clogging, V < 1	Moderate Abrasion V > 3	> 25% increase in Downstream Velocity	
22	southeast edge of the Helo Pad	7	0.6%	0.3 m (12 in.) 78.2 m metal	moderate	heat trace; inflow end was covered in fines and under a standing pool of water (2009–2010)	√		√	√			√	provide scour protection at inlet and outlet; build up area downstream of outlet to modulate increased downstream velocities; undersized, so increase size and roughness (slows velocities) if scheduled for replacement
23	Gasoline Alley across from Fleet Ops Pad 2	2	21%	1 m (36 in.) 6.5 m corrugated metal	working	ice and soil obstruction on the bottom; could be a problem in accommodating the runoff during an extreme event; bottom covered with ice and soil	√		√	√		√		provide scour protection at inlet and outlet; dig in area upstream to slow velocities and provide relief during extreme events; undersized, so consider multiple culverts if replaced
24	Hut Point Rd	1	7.2%	0.61 m (24 in.) ~17.5 m corrugated metal	moderate	high pressure water used in 2009–2010 to remove large buildups of ice				√				provide scour protection at outlet
25	Ice Pier Road	1	89%	0.61 m (24 in.) 17.5 m corrugated metal	moderate		√	√	√	√				undersized; increase cover to minimum, provide scour protection at inlet and outlet

Culvert	Location/Crossing Description	Sub-Basins Conveyed	Runoff Conveyed	Dimensions: Diameter Length Type	Physical Condition	Ice Conditions and Signs of Physical Decay	Quantitative Criteria							Possible Solutions
							Below Capacity, HW/D > 1	Under-designed Cover < 0.45	Scour Likely Upstream, V > 1.6	Scour Likely Downstream, V > 1.6	Likely Clogging, V < 1	Moderate Abrasion V > 3	> 25% increase in Downstream Velocity	
26	backside of Dorms 203, not marked		4.3%	0.61 m (24 in.) unknown corrugated metal	good	newly installed in 2009–2010								
27	Arrival Heights Road near the Soil Cooker			0.61 m (24 in.) unknown corrugated metal	poor	clogged easily; undersized								increase size or increase slope to increase flows and reduce clogging; provide protection from increased velocities
#		2	4.3%	1 m (36 in.) 12 m corrugated metal	unknown			√	√	√		√		provide scour protection at inlet and outlet; modulate in culver velocities to prevent abrasion by smoothing slope at inlet or providing ponding areas upstream; increase cover to minimum

Figure 9. Existing culvert locations.

2.3.3 Sediment ponds

We highly recommend implementing and constructing sediment ponds (Figure 10) to contain the snowmelt and to slow down the flow in drainage channels. The sediment ponds for sub-basins 1, 2, and 3 were designed as oversized water collection basins with a surface overflow outlet. We recommend investigating the ability to excavate out a larger sediment pond at site 1 and reviewing methods to maintain a pond at that site. Potential sites near 3C should be further explored through borings or small excavations. Table 4 summarizes the recommended dimension ranges for the sediment ponds, and orientation in Figure 9 may varying depending on the topographic and surface information discovered at each location.

Figure 10. Proposed sediment basin locations.

Table 4. Recommended design ranges for sediment ponds.

Design Parameters	Units	Pond 1	Pond 2C	Pond 3C
L_{pond}	m	55–107	122–229	91–213
W_{pond}	m	24–32	46–152	46–91
$D_{settling}$	m	3.4–6.9	1.8–5.3	0.7–3.
$D_{storage}$	m	1.7–3.7	0.7–2.7	0.8–1.5
D_{total}	m	6.8–12.4	4.5–9.7	3.2–6.2
$D_{overflow}$	m	0.9	0.9	0.6
$W_{overflow}$	m	4.6	3.	4.6
$T_{retention}$	hr	40	40	40
Q_{out}	m^3/s	0.052	0.328	0.074
Vel_{out}	cm/s	0.627	5.877	1.984
$Vol_{storage}/Vol_{in}$		216%–233%	678%–735%	219%–530%
$Vol_{storage+settling}/Vol_{in}$		652%–713%	2048%–2804%	655%–1007%
Q_{out}/Q_{in}		16.8%–18.4%	16.8%–260%	16.8%–18.4%
Vel_{out}/Vel_{in}		1.18%	1.6%	0.48%

L_{pond} = Pond length
$D_{setting}$ = Settling depth
$D_{storage}$ = Storage depth
D_{total} = Total depth
$D_{overflow}$ = Overflow depth
Q_{out} = outflow discharge
Q_{in} = inflow discharge
$T_{retention}$ = Retention Time
Vel_{out} = outflow velocity
Vel_{in} = inflow velocity
Vol_{out} = outflow volume
Vol_{in} = inflow volume
$Vol_{settling}$ = Settling volume
$Vol_{storage}$ = Storage Volume
W_{pond} = Pond width
$W_{overflow}$ = overflow width

2.3.4 Sediments and pollutants

During the 2010–2011 austral summer, 89% of runoff (estimated total volume of 267,700 m^3 of water) discharged into WQB (Affleck et al. 2014a). From the calculations based on sediment transport in flow, almost 99.5% of the basin's sediment discharges into WQB (Affleck et al. 2014c). This can be decreased by installing the settling ponds and flow control weirs and by rerouting to the new flow paths.

Given that the snowmelt runoff contained significant concentrations of heavy metals and certain PAHs, prevention and mitigation are crucial for reducing contamination at McMurdo Station. Human factors, such as awareness, caution, improved chemical handling, and environmentally friendly practices, can have an important role in reducing contamination. Engineering methods, such as best management practices or erosion control systems (sediment ponds and weirs) (Affleck et al. 2014b and 2014c), can also mitigate further contamination. Given the proper implementation in this unique environment, these systems can improve water quality and can reduce pollutant discharges by allowing these elevated level of contaminations to degrade with time.

2.3.5 Snow dump locations

McMurdo Station is in operation all year. Although the operation is limited in the winter, snow clearing is necessary when significant snow fall occurs. Around the Station, snow is normally cleared from roads, pathways and pads, and around the buildings for pedestrian and vehicle access. The snow pile locations are critical as they affect the snowmelt and the hydrology of the watershed when temperatures warm in the summer. The key is to identify the appropriate snow dump locations where the resulting meltwater will not contribute to the runoff conveyed through McMurdo Station. In particular, snow dumps should not be placed at locations where the resulting runoff would intersect areas of known soil contamination. Results from this assessment will be incorporated into the SOP for best practice to mitigate drainage and sediment erosion issues.

Figure 11 shows the two recommended locations for snow disposal. The more snow is disposed of away from the Station, the less runoff will impact the drainage system and discharge into WQB. Based on the topo map and the 2009–2010 drainage field study (Affleck et al. 2012a), the following are the preferred snow dump locations:

- On the sea ice in McMurdo Sound as long as the snow is clean (no soils)
- The south side of the Pass (behind Ob Hill and towards Scott Base) for the rest of the snow

Upon melting, this snow would not flow through town but down directly into the sound.

3 Practices and Procedures

This SOP applies to the current drainage system (without any alteration at the Station). We suggest that staff involved in implementing this SOP note procedures and practices that work for them and any methods or ideas that improve on these preliminary recommendations, particularly as relates to efficiency and safety.

3.1 Snow dumping

3.1.1 General best management practices (during winter months)

a. Snow must NOT be temporarily stored or piled up on the drainage system or in areas that will obstruct the drainage.

b. Snow must NOT be place at locations where the resulting melt will drain to or through contaminated areas.

c. Snow must NOT be placed along channels or in ditches.

d. Snow must NOT be pushed on the ditches while clearing the roads.

3.1.2 Removal areas

Snow is to be cleared from roads, pathways and pads, and around buildings where pedestrian and vehicle access is needed.

3.1.3 Disposal locations

a. Disposal is allowed in only the designated areas shown below in Figure 11.

b. Careful attentions should be paid to whether the snow is clean enough to dispose of in a certain location.

c. Snow dumped on the sea ice in McMurdo Sound must be clean (no soils).

d. Other snow must be placed on the south side of the Pass (behind Ob Hill and towards Scott Base).

Figure 11. Snow dump locations.

3.2 Drainage channels

3.2.1 General best management practices (during summer months before snow melting occurs)

a. Snow must NOT be placed along channels or in ditches.

b. Snow must NOT be pushed on the ditches while clearing the roads.

c. Vehicles must NOT drive along the channels or cross the channels.

3.2.2 Snow clearing in channels and drainage ditches

a. Start in late October to mid-November.

b. Clear the ditches and culvert starting from the bottom of the Station and working uphill.

c. Maintain original side and bed slopes during the clearing efforts.

d. Shape the channels to minimize disturbance and to maintain the original shape as a scour and erosion control best practice.

e. Tools include
   (1) available or appropriate heavy equipment in accessible areas and
   (2) manual clearing (shoveling) in tight places.

f. Place cleared snow and ice in appropriate snow dumping location according to Section 3.1.3.

3.3 Weather monitoring (during winter months)

a. Monitoring weather is important for determining when to prepare the site for high flow events.

b. CRREL developed a spreadsheet using the climate data available at McMurdo Station to estimate when the peak discharge could occur. Directions are listed in the spreadsheet as shown in Figure 12.

c. At the beginning of the season, prepare a new page in the spreadsheet for this water year (November–March).

d. On a regular basis, download from SPAWAR (or Antarctic Meteorological Research Center) daily peak temperatures and average cloud cover.

e. Input that data into the spreadsheet, monitor indicated likely high flow event dates, and take recommended measures to prepare (see Figures 12 to 14).

Figure 12. Instruction for the Peak Flow Prediction Worksheet.

Directions
type in water year in column B1
Add temperature, Clearness to table blow (in yellow, will be automated eventually)
Expected Peak Flow will appear in table in green for past dates, red for within 7 days of today or in future
Add Observed Peak Q dates to table below (in yellow) for comparision - matches will show in top table in blue

Figure 13. Input table for the Peak Flow Prediction Worksheet.

Date	Max Temp °C	Clearness %	Date Of Q Peak Observed	Max Clearness 3 days	T_{max} > 0.25 °C	Local Maxima of T_{max}?	Max Clearness > 25% 3 days		Peak Temp Event Number	ATDD °C - days	Δ ATDD 3 days
11/1/2013	(11.00)		11/1/2013							0.000	
11/2/2013	(11.00)	24%								0.000	
11/3/2013	(11.00)	24%		24%						0.000	
11/4/2013	(12.00)	21%		60%	0	0	0		0	0.000	0.000
11/5/2013	(14.00)	60%		60%	0	0	1		0	0.000	0.000
11/6/2013	(17.00)	44%		60%	0	0	1		0	0.000	0.000
11/7/2013	(15.00)	46%		46%	0	0	1		0	0.000	0.000
11/8/2013	(6.00)	9%		46%	0	1	0		0	0.000	0.000
11/9/2013	(8.00)	3%		9%	0	0	0		0	0.000	0.000
11/10/2013	(10.00)	8%		11%	0	0	0		0	0.000	0.000
11/11/2013	(13.00)	11%		19%	0	0	0		0	0.000	0.000
11/12/2013	(8.00)	19%		19%	0	0	0		0	0.000	0.000

Figure 14. Output table for the Peak Flow Prediction Worksheet.

	Peak Temp Date	Max Temp	Clear-ness	Δ ATDD 3days>0	Predicted Lag Days		Expected Peak Flow Date	Range	Match to an observed Peak Q?			
		°C	%		Average	Range				Q_{peak} Date	closest date	days out of range
1	11/21/2013	-4.00	18%	0.00	16.5	12.8 - 20.1	12/7/2013	(12/03 - 12/12)		-	11/1/2013	-32
2	11/24/2013	-2.00	13%	0.00	16.5	12.8 - 20.1	12/10/2013	(12/06 - 12/15)		-	11/1/2013	-35
3	12/11/2013	0.00	91%	1.00	14.9	11.2 - 18.6	12/25/2013	(12/22 - 12/30)		-	11/1/2013	-51
4	12/18/2013	3.00	76%	3.00	12.2	8.5 - 15.8	12/30/2013	(12/26 - 01/03)		-	11/1/2013	-55
5	12/25/2013	-2.00	35%	0.00	16.5	12.8 - 20.1	1/10/2014	(01/06 - 01/15)		-	11/1/2013	-66
6	12/27/2013	2.00	50%	4.00	11.0	7.3 - 14.7	1/7/2014	(01/03 - 01/11)		-	11/1/2013	-63
7	1/2/2014	6.00	90%	11.00	5.4	1.8 - 9.1	1/7/2014	(01/03 - 01/12)		-	11/1/2013	-63
8	1/7/2014	2.00	42%	5.00	9.9	6.3 - 13.6	1/16/2014	(01/13 - 01/21)		-	11/1/2013	-73
9	1/13/2014	3.00	30%	5.00	9.9	6.3 - 13.6	1/22/2014	(01/19 - 01/27)		-	11/1/2013	-79
10	1/17/2014	1.00	66%	2.00	13.5	9.8 - 17.1	1/30/2014	(01/26 - 02/04)		-	11/1/2013	-86
11	1/21/2014	1.00	5864%	2.00	13.5	9.8 - 17.1	2/3/2014	(01/30 - 02/08)		-	11/1/2013	-90
						-				-		

3.4 Culverts

3.4.1 General best management practices

a. Use rocks, such as rip rap (rock with a diameter less than or equal to 10 cm [4 in.]), for energy dissipation at the inlet and outlets of culverts where scour will likely occur.

b. Raise roads or dig new culverts where the road cover is less than 0.45 m (Culverts 5, 9, 11, 12, 24, and 25).

c. Frequently replace or reduce culvert velocities where moderate culvert abrasion is likely (Culvert 1).

d. Increase the size of under-capacity culverts when they are replaced (Culverts 24, 25, and 27) with culverts that are durable in cold climates.

e. For slow velocity culverts that may lead to clogging, increase culvert velocity by raising the upstream channel invert (Culvert 11 and 15).

f. When an excessive increase in downstream velocity exists (specifically at Culverts 1 and 16), increase roughness by building up the upstream bed.

3.4.2 Culvert winter maintenance

a. Finish digging out culvert inlets and outlets by mid-November.

b. Remove the ice or debris in culverts, especially along major drainage (along the Main Road and Gasoline Alley) before the first week of December. Manual clearing may be required, especially in tight areas with intercepting utilities.

c. Pay special attention to these culverts: 1–4, 6, 8, 11–13, 16, 17–22, 24, 25, and 27. Some of these culverts are undersized, vulnerable for ice build-up, and in poor conditions. Replacing these culverts with culverts that are durable in cold climates, highlighted in Table 3, is necessary.

d. Remove ice in culverts by ice chipping or by a regular acceptable blasting method. A more efficient way of ice removal is by using heat injection or by properly installing a heat trace system.

e. In early February, to minimize snow and ice build-up inside the culvert, plug the ends of the culverts with an actual cap (as opposed to snow) before winter hits.

3.5 Flow controls

3.5.1 Temporary weirs (installation and removal)

a. To filter sediment and to attenuate or control the flow, per recommendations in Table 2, install weirs along the channels highlighted in red circles (which are along 2BU, 2CD, 2CU, 3A, 3B, 3C, and 6) in Figure 5.

b. By the end of the first week of December, install flow controls in the designated channels after the channels are cleared of snow and ice.

c. Remove flow controls by the end of the peak runoff season, around the end of January or the first week of February.

3.5.2 Rock weir installation procedures

a. To provide support and to further slow down the flow through the weir, dig a 10–15 cm (4–6 in.) deep channel out of the ground beneath where the weir will be (Figure 15).

b. Place a geotextile fabric sheet under the actual dam structure; and place another sheet over the dam, covering from the toe to the heel of the dam, enclosing the rock pile materials. This fabric will help keep the shape of the dam and filter out sediment.
   (1) Extend the edges of the fabric at least 15–18 cm (6–7 in.) beyond the actual structure and bury it in 10 cm (4 in.) deep holes, refilling them with gravel or rock.

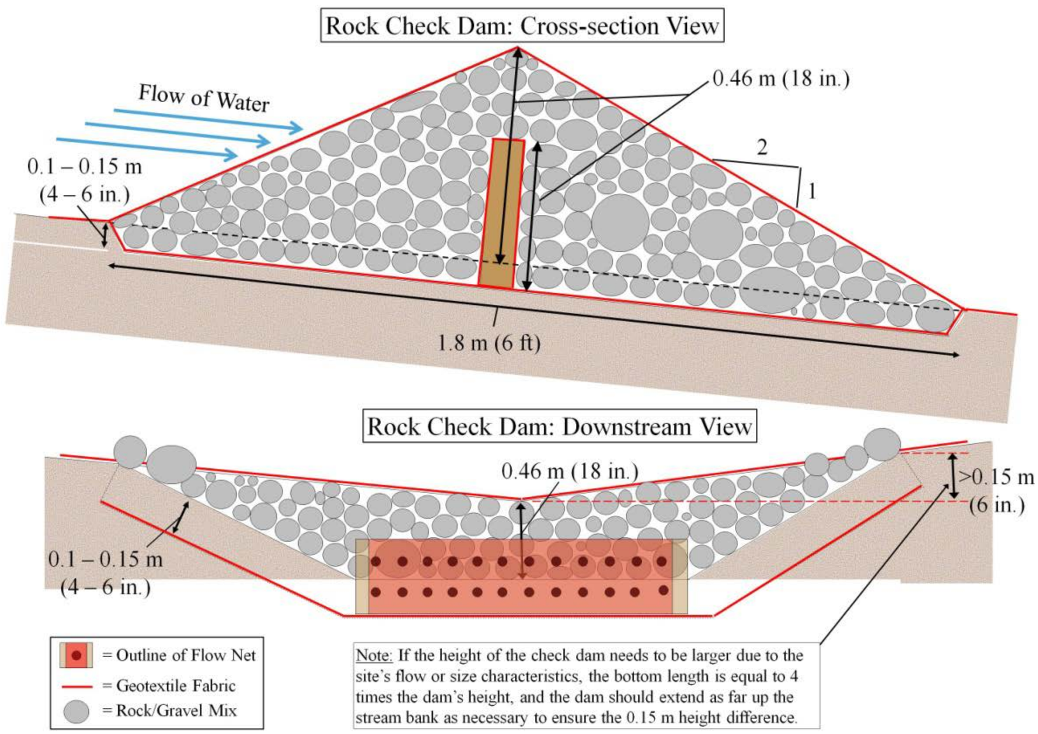
c. Place a flow net of wood in the 1.4 m (4.5 ft) deep channel.
   (1) Nail together edge to edge two 5 × 20 cm (or specifically U.S. standard 2 × 8 in.) boards.
   (2) Drill holes into the wood for through flow.
   (3) Cover the holes with geotextile.
   (4) Place it in the channel prepared in an earlier step.

d. Place rock.
   (1) Use loose rock 15–30 cm (6–12 in.) in diameter, free of fines and sands, well graded, and underlain with a geotextile to reduce seepage.
   (2) Place the rock so the center of the dam is approximately 46–60 cm (18–24 in.) high at the center of the channel.
   (3) Ensure the middle of the dam is at least 15 cm (6 in.) lower than the height of the wall on the sides.
   (4) The height of each side will vary from site to site to ensure that they are at least 15 cm (6 in.) higher than the center. The purpose of this is to direct the flow of water inward towards the middle of the dam and not outward along the banks, which would erode the stream banks.

(5) Keep the decline from the edges to the middle as gradual as possible.
(6) Prevent the slope of the upstream and downstream sides of the dam from being steeper than 0.5.

e. Dig sumps upstream of the check dam to provide a larger basin for water to collect in. The sumps should be 0.3 m (1 ft) deep and 1.2 m (4 ft) long, spanning across the whole stream bed. The downstream edge of each sump should be at least 1 m (3 ft) upstream from the front edge of the dam.

Figure 15. Standard design for a rock check dam (not drawn to scale).



3.5.3 Wooden weir installation procedure

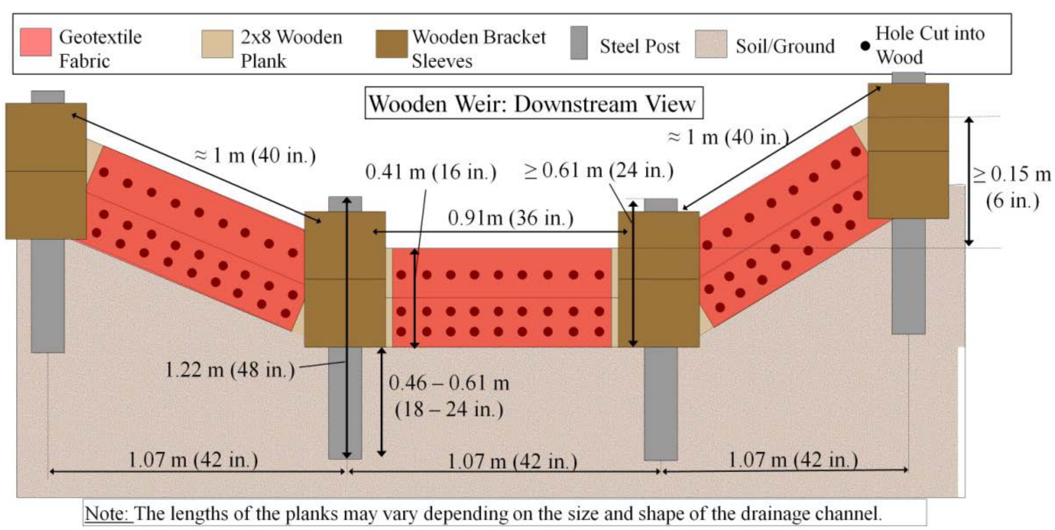
Material for the wooden weir consists of U.S. 2 × 8 in. boards that are connected to each other by bracket sleeves (Figure 16). The Appendix details material preparation.

a. Install each schedule 40 steel post approximately 100 cm (42 in.) away from each other horizontally and in as straight of a line as possible.
(1) Dig the posts into the ground approximately 46–60 cm (18–24 in.) deep.
(2) They will stay in place throughout the whole year.

b. Install wooden bracket sleeves over the steel posts.

c. Install center and bank planks into a 15 cm (6 in.) wide channel in the brackets.
   (1) The boards are designed to have small drilled holes to allow and control water flow, providing a level of porosity through the weir. (The hole distributions for the top are 10 cm [4 in.] apart along the center of the board, and bottom planks have doubled the number of holes spaced at 10 cm [4 in.] apart.)
   (2) Orient the planks so the geotextile screen side faces upstream.
   (3) If a plank comes into the channel at an angle, use a 5 × 10 cm piece of wood (U.S. 2 × 4 in. board), or other pieces of wood, to fill in the gaps in the channel to make contact between the planks and bracket. This wood can be nailed or screwed into the bracket to make sure that all the pieces are secure and do not come loose.
   (4) Due to the variation in the shape of the channels, the wooden planks may not fit flat against the ground. To fix this, build a small triangular wall of rocks or gravel on the upstream side of the weir. This formation will be approximately 15 cm (6 in.) tall and will span the entire weir.
   (5) Similar to the rock catch dam, the center planks should be at least 15 cm (6 in.) lower than the edge of the planks and brackets on each side of the dam.
   (6) If this height difference is not achieved, it may be possible to slide a third set of planks into the brackets along the banks of the channel.

Figure 16. Standard design for wooden check dam or similar approach (not drawn to scale).



3.6 Sediment ponds

a. Before mid-November, perform an annual inspection for sediment deposition, side-slope erosion, and damage to the outfall.

b. To check the conditions, inspect the sediment ponds after each high flow event.

c. Remove sediment deposits when they reach one-half the height of the outfall.
   (1) Do not deposit the sediment downstream from the embankment, adjacent to a stream, or in a floodplain.
   (2) Clean out ponds every 1–2 years.

3.7 Ground modification and new construction (site work, slope, and landscaping)

a. Before placing or remodeling buildings, site preparation is imperative. This includes earthwork, slope stability, and many other geotechnical considerations.

b. Ensure that proper design and improvements are incorporated so that there will be minimal disruption upstream and downstream for drainage.

c. Minimize trap areas for snow and ice buildup that impedes drainage. This is critical due to the topography and the environmental uniqueness.

d. To convey runoff and melt water away from existing and new structures, it is important to properly design and grade areas near buildings.

e. Limit erosion, flooding, and excessive sediment deposition.

f. Maintain the recommended side slope in channels and embankments at McMurdo Station at 2:1 (horizontal:vertical) or 27° slope for loose gravel with sand materials.

g. Stabilize steep banks by using riprap, gabion, or geocomposite lining with gravel.

h. To ensure proper soil compaction with ice content and appropriate bank design, specifically the side slope for frozen soils, follow correct construction practices.

i. Satisfactorily compact soils at the Station even at low temperatures and low moisture content. The required frozen density may be equal to the maximum unfrozen density with low moisture content. These areas require thorough surveying, geotechnical engineering, and maintenance attention, including proper grading, landscaping, and compaction of ice-rich soils.

4 Way Forward

We anticipate that this SOP will evolve as staff members involved in implementation of the SOP improve practices as necessary to reduce the erosion of material (soils or fines) by the snowmelt runoff, to control the flow in channels during extreme runoff events, and to adopt applicable engineering and maintenance practices.

Future development at McMurdo Station is likely to occur over time to increase operational efficiency, function, and reliability and to reduce the footprint. Potential improvements to the drainage systems are also likely to occur when future developments are implemented, thus drainage should be incorporated into future plan and development. Though this SOP is written broadly, revision may be necessary if new elements are added that do not fit within the specified procedures.

The sources of contamination should be dealt with on a case by case basis to eliminate the causes of pollution. Eliminating the source is the most efficient way of reducing the effects of pollution migration. Dealing with the problem downstream at the final destinations will be more costly and labor intensive for operations.

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Appendix A: Wooden Weir Material Assembly and Preparation

a. Gather and cut to size the following materials:
   (1) Spruce 2 ×8 in. rough sawn planks
      - Six 40 in. long planks
      - Two 3 ft long planks
      - Three 16 in. long planks
   (2) 2 in. diameter Schedule 40 steel posts
      - Four 4 ft long posts
   (3) Twenty 12 in. Lag bolts
   (4) Tencate Mirafi Woven Monofilament FW402 geotextile fabric
      - One 22 × 36 in. sheet
      - Two 28 ×40 in. sheets
   (5) Staples and nails for securing the fabric to the wood
   (6) 5–7 ft^3 of rock for triangular ramp at the upstream base of the dam

b. Drill holes in the top and bottom planks.

c. Staple or nail geotextile fabric to what will be the upstream side of the weir.

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Engineering for Polar Operations, Logistics, and Research (EPOLAR)

14. ABSTRACT

During the austral summer, the snowmelt runoff at McMurdo Station is quite unique and variable. As the temperature gradually warms up, McMurdo staff clears winter snow and ice accumulation in the drainage channels to accommodate the incoming snowmelt runoff. This ephemeral flow is observed as diurnal daily fluctuation throughout the austral season and varies depending on the air temperature and many other factors. In addition, the runoff mobilizes sediment that is washed into these channels and transports contaminants into to Winter Quarters Bay and McMurdo Sound. The overall goal of this document is to provide guidance for operation and maintenance of in-town roads and the drainage system. The processes and steps referred to in this document require further verification to incorporate lessons learned and to promote appropriate best practices.

15. SUBJECT TERMS

	Erosion	Slope stability
Drainage	Runoff	Snowmelt
EPOLAR	Sediment ponds	Weirs

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